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Grid-Tie Photovoltaic Power System Feasibility Study and the Comparison of Realized Energy: A Practical Case Study

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Abstract **– In this study, the results derived from the mathematical model proposed during the feasibility stage and the energy obtained from the annual monitoring period of an energy commission system have been compared. In the study, the feasibility study of the before set-up and start-up of the 60 kWp grid-tie photovoltaic power system at Manisa Turgutlu Chamber of Commerce andIndustry and the energy outcome after the one year period of monitoring following the start-up have been compared, the deviations have been determined and the accuracy of the mathematical model applied during the feasibility study has been examined.**

Keywords **– Energy Policy Turkey, Solar Energy, Green Electricity, Renewable Energy, Photovoltaic.**

I. INTRODUCTION

In 2015, 20% of global energy requirements have been met with applications according to renewable energy sources. Approximately half of this 20% consists of modern renewable energy applications. Worldwide modern renewable energy applications gather around 4 main requirements. These can be named as electric energy production, heating and cooling, transportation and the applications at the countryside which are off grid. By the end of 2015 when worldwide energy applications are studied, fossil fuel is at 78,3% and nuclear energy is at 2,5%, whereas modern and traditional renewable energy applications' total is at 19,2%. When we look at the modern renewable energy applications in 2015 on a global basis 4,2% is biomass, geothermal and solar power; 3,9% is hydroelectric applications; 1,4% is solar, wind, biomass and geothermal sourced electric energy production applications and 0,8% is biomass [1] (Refer to Figure 1).

Fig.1 The share of renewable energy application in the world by 2015.
Source: Renewables 2016 Global Status Report

If we look at the same chart in view of electric energy production, we can see that at the end of 2015 within the worldwide total electric energy production, renewable resources are at 23,7%. When we look at only the photovoltaic application, this rate is at around 1,2% [1] (Refer to Figure 2).

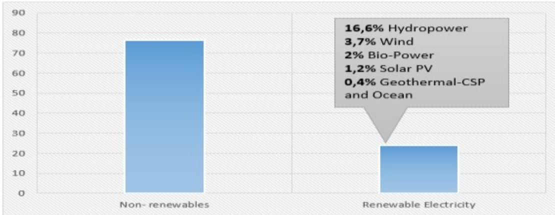

Fig.2 The share of renewable energy in electricity generation applications in the world by 2015
Source: Renewables 2016 Global Status Report

2015 is an historic year for the PV industry and with the additional 50GW new PV set-up the total worldwide PV set energy has reached 227 GW [1] (Refer to Figure 3).

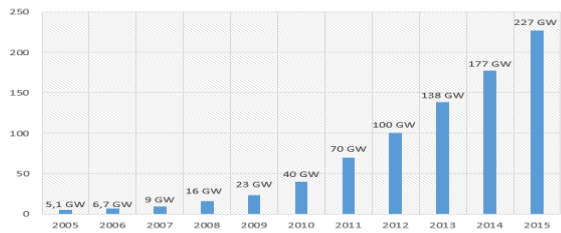

Fig.3 The development of photovoltaic installed capacity in the world
Source: Renewables 2016 Global StatusReport

When we look at the distribution of the total PV set-up worldwide by countries it can be seen that China, who has come a long way and reached a capacity of 45GW is in first place. With 1,5GW new increase in capacity Germany comes right after China with a total of 41GW PV set-up power [1] (Refer to Figure 4).

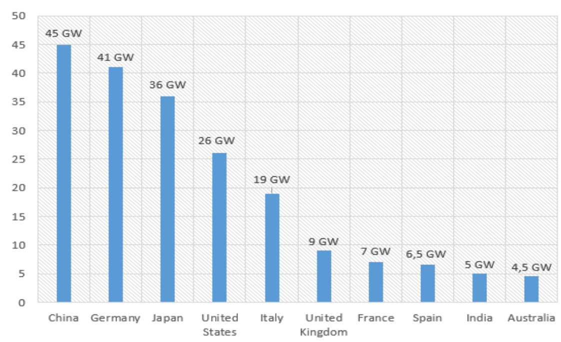

Fig. 4 Total PV installed capacity in the world on the basis of the countries
Source : Renewables 2016 Global Status Report

In the PV Technology Roadmap report published by the International Energy Agency in September 2014, it has been reported that the recent energy production worldwide consists of 78% fossil fuel and 20% renewable energy. When future projections are studied, it is thought that by 2050 this rate will be 65-79% renewable and 20-12% will originate from fossil.

In addition to this research, when we look at the worldwide situation by the end of 2015 it is seen that 8,1 million people are either directly or indirectly employed in the renewable energy industry. Approximately 2,7 million people worldwide, which is a serious rate, are employed either directly or indirectly in the photovoltaic industry,. Of these people 1,6 million are employed in China.

II. The Outlook of Renewable Energy in Turkey

When we look at the PV industry in Turkey, the installed power of Turkey PV system which was a few MW two years ago has reached 550MW by 2016 and this number increases with each new system engaged. It is foreseen that this number will rapidly increase in the upcoming periods.

Izmir Development Agency has started a support program named "Renewable Energy and Environment Technology" on December 17 2012 and has pioneered mobility by injecting approximately 25.000.000 TL to Turkey's renewable energy industry in general and especially in Izmir. Within this framework, in Izmir, 36 renewable energy systems' (26 solar, 4 wind, 3 solar-wind hybrid, 3 biomass) investment has been supported and approximately 10MW unlicensed electric production facility has been implemented. Within this scope, with renewable power systems installed at many public institutions and private sectors in Izmir, energy production has gravitated towards clean energy resources and public awareness has been formed. With the success of this support many development agencies in Turkey has initiated similar support mechanisms and there has been an awareness and a mobilization in using renewable energy resources in Turkey. After the call for a grant by the Izmir Development Agency, Zafer Development Agency which covers the cities of Manisa-Kutahya, Usak-Afyon has started a similar project and a non-recourse financial support has been given to many renewable energy projects.

The Purchasing Guarantee Based on Renewable Energy Resources in Turkey

The purpose of the incentive system issued on Turkey's renewable energy resources is to extend the use of renewable energy resources in electric energy production, to redound the economy of the resources in a reliable, economic and high quality manner, to increase the resource variety, to minimize the greenhouse gas emission, to utilize waste, to protect the environment and to enhance the manufacturing sector which is needed in order to achieve these purposes. In this context, the purchasing cost relating to the existing purchasing guarantee is shown in Table 1 and Table 2. These tables are from the YEK (High Energy Institution) act and they are under the purchasing guarantee the following ten years after installation.

Table 1. Purchasing figures based on renewable energy sources in Turkey.

Type of generation facility producing renewable energy	Prices to be applied (USD Cent/kWh)
Hydroelectric Power Plants	7.3
Wind Power Plants	7.3
Geothermal Power Plants	10.5
Biomass Power Plants	13.3
Solar Power Plants	13.3

Source: Turkey Renewables Law Schedule 1

Table 2. Contribution figures for domestic manufacturing purchasing guarantee based on renewable energy sources in Turkey.

Type of Generation Plant	Components Produced in Turkey and Additional price incentive (USD Cent/kWh)
A: Hydroelectric Power Plant	1. Turbine : 1.3 2.Generator and Power Electronics: 1.0
B: Plant Generating Electricity from Wind Energy	1. Wing: 0.8 2. Generator and Power Electronics: 1.0 3. Turbine Power: 0.6 4. Entire Mechanical Components in Rotor and Nacelle Groups (Excluding Payments for Wing Group and Generator and Power Electronics): 1.3
C: Plant Generating Electricity Photovoltaic (PV) Solar Energy	1. Production of PV Panel Integration and Solar Structural Mechanics: 0.8 2. PV Modules: 1.3 3. Cells Constituting the PV Modules: 3.5 4. Inverter: 0.6 5. Material on the PV Module that Focuses Solar Ray: 0.5

III. The Mathematical Method Suggested During Feasibility

The mathematical formulation used in the energy harvesting calculation procedure is described below [13]:

$$E_{PV,m} = I_{opt,m} \cdot \eta_{sys}$$

where monthly based daily solar energy generation from 1 m^2 photovoltaic array during the month m is $E_{PV,m}$ with system efficiency η_{sys} and $I_{opt,m}$ (Wh/m^2) is daily total solar radiation in month m, E_g (Wh) is daily energy demand, $\eta_{sys}$and required total PV module area is A_{PV}, which is given by: $A_{PV} = \frac{E_g}{I_{opt} \cdot \eta_{sys}}$

$$\eta_{sys} = \eta_m \cdot \eta_{bat} \cdot \eta_{pve} \cdot 0{,}9$$

whereη_m is the module efficiency, η_{bat} is the battery storage efficiency, η_{pve} is the power electronics efficiency, and the 0.9 is the other (cable etc.) efficiency [8].

The model in 3.1 has been fictionalized for the equation in order to calculate the annual electric energy outcome obtained by solar energy photovoltaic method.

$$G = \eta_{PV} \sum_{k=1}^{8760} I_k \qquad (3.1)$$

η_{PV}: *Conversion efficiency of a photovoltaic system*

I_k: the total solar radiation in k. Time, kWh / m^2
G: Annual energy harvesting for $1m^2$ photovoltaic module.
In this model, Effect of temperature on Conversion efficiency of a photovoltaic system is *calculated by equation 3.2.*

$$\eta_{PV} = \eta_{inv} . \eta_c . \eta_r . [1 - \beta . (T_c - T_r)] \quad (3.2)$$

η_r = module efficiency, which is expressed by the module manufacturer,
η_{inv} = Inverter efficiency,,
η_c = DC and AC cable efficiency,
β = String efficiency temperature coefficient,
T_c = Monthly average cell temperature,
T_r = Reference temperature declared for cell efficiency.

In this model it can be seen that not only the temperature but also other system components cause a loss in the final conversion efficiency. In the model, inverter, DC and AC cables and the loss as a result of dust has been taken into consideration and final system efficiency has been reached according to the effects of these.

IV. The Solar Power Potential for TUTSO (Turgutlu Chamber of Commerce And Industry) and the Feasibility of 60kW Photovoltaic Energy System

When Turgutlu solar energy potential is taken into consideration it is understood that the best inclination angle is 32ºand that the calefaction per unit area when a photovoltaic module is placed at this angle is approximately 5 550 Wh/m^2/day (Refer to Table 4 and Figure 5). This is 1,5 times more than Turkey's average, which is 3 600 Wh/m^2/d. On this basis, the electric energy production potential and the initial investment cost period of a photovoltaic energy system placed in Turgutlu will be advantageous in proportion to Turkey's average.

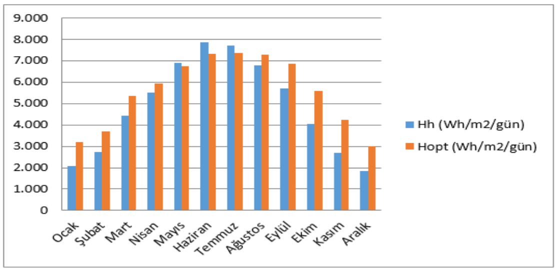

Fig.5 Comparison of Irradiation on horizontal plane (Wh/m2/day) and Irradiation on optimally inclined plane (Wh/m2/day)
Source: European Commission Joint Research Center for Photovoltaic Geographical Information System (PVGIS E JRC)[10].

Table 3. Overview of 60kW PV Systems

City	Manisa
Data Source	PVGIS
PV Installed Power	60kW$_p$
PV Module Total Surface Area	500 m^2
Total Number of PV Modules	240 piece of Yingli Solar YLC250P Model
Total Number of Inverters	3 piece of SMA 20000TL Model
Panel Installation Angle	15º

Table 4.Turgutlu solar radiation potential and the average monthly electricity production for 60 kWp PV System

Months	H_h Wh/m^2/day	H_{opt} Wh/m^2/day	I_{opt}	E_m (kWh)/60 kWp	E_r (kWh)/60 kWp
January	2 080	3 210	60	3 999,00	3 680,00
February	2 720	3 710	52	4 368,00	4 056,00
March	4 430	5 370	41	7 285,00	6 980,00
April	5 510	5 930	26	8 040,00	9 600,00
May	6 890	6 740	13	9 641,00	9 000,00
June	7 870	7 330	7	10 170,00	8 690,00
July	7 720	7 360	10	10 262,00	11 500,00
August	6 790	7 290	22	9 743,00	8 900,00
September	5 710	6 840	37	8 580,00	7 600,00
October	4 050	5 580	50	6 913,00	6 100,00
November	2 680	4 250	60	4 890,00	3 590,00
December	1 860	2 990	62	3 658,00	2 860,00
Average	4 859	5 550	32		
Expected and Actual Amount of Annual Electricity Generation (kWh)				**87 570,00**	**82 556,00**

Hh : Irradiation on horizotal plane (Wh/m^2/day)
Hopt : Irradiation on optimally inclined plane (Wh/m^2/day)
I_{opt}: Optimal inclination (deg.)
E_m: The expected annual electricity production for 60kWp PV System
E_r: The Actual annual electricity production for 60kWp PV System

The general view of a 60kW photovoltaic energy system placed facing southeast at a 15⁰ panel inclination and with a 10º shift is shown in Figure 6.

Fig.6 After installation overview of 60 kWp PV System

The annual average electric energy production foresighted for the photovoltaic energy system built in Turgutlu, which is shown in Figure 6, was to be 87 570,00

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kWh according to the calculations and the feasibility studies before set-up but upon observations in the first year after set-up the energy outcome showed 82 556,00kWh. When the calculation model set forth and the feasibility studies which were done in accordance with the model are compared it is seen that there is a 5,7% deviation. The accuracy of the model is 94,3%. In this scope, as a result of the feasibility study, the monthly production amount based on the model and the monthly real energy outcome of the system are shown in Figure 7.

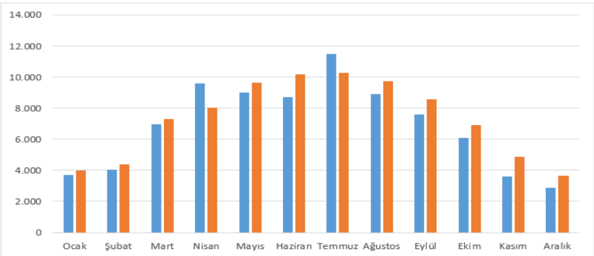

Fig.7 Expected and actual monthly electricity production values for 60kWp PV System

Source: European Commission Joint Research Center for Photovoltaic Geographical Information System (PVGIS E JRC)

V. Conclusion

The cash flow statement (Refer to Table 5) which has been prepared according to the information received that the turnkey installation of the 60kW photovoltaic system in Turgutlu is $101 993,30 (inc. VAT)it has been concluded that the reimbursement period will be approximately six and a half years. During these calculations it has been noted that the electric energy produced in the system has been set-off to the electric consumption at the TUTSO building and it has been foreseen that the annual attrition rate would be 1,5% and the increase in the network electric price would be 10% annual.

Table 5. Annual Statement of Cash Flow Basis for 60 kWp Photovoltaic Power System

	1st year	2nd year	3rd year	4th year	5th year
Investment Cost.-$	-$101 993,30	$0,00	$0,00	$0,00	$0,00
Annual Energy Production.-kWh	82 556,00	81 978,11	81 404,26	80 834,43	80 268,59
Grid Price.-$	$0,14	$0,16	$0,17	$0,19	$0,21
Annual Cash Flow.-$	$11 833,03	$12 925,22	$14 118,21	$15 421,32	$16 844,71
Cumulative Cash Flow.-$	-$90 160,27	-$77 235,06	-$63 116,85	-$47 695,52	-$30 850,81
	6th year	7th year	8th year	9th year	10th year
Investment Cost.-$	$0,00	$0,00	$0,00	$0,00	$0,00
Annual Energy Production.-kWh	79 706,71	79 148,76	78 594,72	78 044,56	77 498,25
Grid Price.-$	$0,23	$0,25	$0,28	$0,31	$0,34
Annual Cash Flow.-$	$18 399,48	$20 097,75	$21 952,77	$23 979,01	$26 192,28
Cumulative Cash Flow.-$	-$12 451,33	$7 646,42	$29 599,19	$53 578,20	$79 770,48
	11th year	12th year	13th year	14th year	15th year
Investment Cost.-$	$0,00	$0,00	$0,00	$0,00	$0,00
Annual Energy Production.-kWh	76 955,76	76 417,07	75 882,15	75 350,97	74 823,52
Grid Price.-$	$0,37	$0,41	$0,45	$0,49	$0,54
Annual Cash Flow.-$	$28 609,82	$31 250,51	$34 134,93	$37 285,59	$40 727,05
Cumulative Cash Flow.-$	$108 380,30	$139 630,81	$173 765,75	$211 051,33	$251 778,38
	16th year	17th year	18th year	19th year	20th year
Investment Cost.-$	$0,00	$0,00	$0,00	$0,00	$0,00
Annual Energy Production.-kWh	74 299,75	73 779,65	73 263,20	72 750,35	72 241,10
Grid Price.-$	$0,60	$0,66	$0,72	$0,80	$0,88
Annual Cash Flow.-$	$44 486,15	$48 592,22	$53 077,29	$57 976,32	$63 327,53
Cumulative Cash Flow.-$	$296 264,53	$344 856,76	$397 934,04	$455 910,36	$519 237,90
	21st year	22nd year	23rd year	24th year	25th year
Investment Cost.-$	$0,00	$0,00	$0,00	$0,00	$0,00
Annual Energy Production.-kWh	71 735,41	71 233,27	70 734,63	70 239,49	69 747,81
Grid Price.-$	$0,96	$1,06	$1,17	$1,28	$1,41
Annual Cash Flow.-$	$69 172,67	$75 557,30	$82 531,24	$90 148,88	$98 469,62
Cumulative Cash Flow.-$	$588 410,57	$663 967,87	$746 499,11	$836 647,99	$935 117,60

As can be seen from the cash flow statement, the system pay back itself in 6.5 years and the end of the 25th years, financial benefits to investors of the system is estimated to be $ 935117,60.

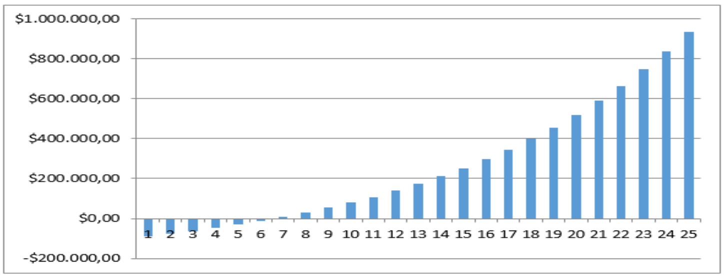

Fig. 8. Annual Basis Depreciation Chart for 60 kW Photovoltaic Power System

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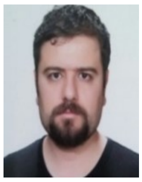

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